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Experimental Study of Venous Grafts with Special Reference to Rigidity and Non-Suture Technique

by

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I INTRODUCTION

It is one the earnest desires of surgeons engaged in vascular surgery or organ transplantation to develop a venous prosthesis and technique for vascular reconstruction which are at least as patent as in the arterial system. Although prosthetic materials for arterial grafts are now available for clinical use, venous replacement has continued to present a problem. The lower blood pressure, slower blood flow and abundant collaterals in the venous system favor the occlusion of venous prostheses. There are two patterns of occlusion of venous replacements as pointed out by SUGIE¹⁾: occlusion with clot formation and early thrombosis occurring immediately after grafting and gradual occlusion due to thickening and constriction of the tissue. Considerable research has been reported on the prevention of occlusions such as elevation of venous blood pressure by a surgically created arterio-venous fistula²⁾, several electrical devices to prevent the adherence of thrombocytes to the venous graft³⁾⁴⁾, coating the inner surface of the prosthesis⁵⁾, etc.. Nevertheless, a satisfactory venous prosthesis has not yet been developed.

My coworker YAMAMOTO and I attempted abdominal vena cava grafts in dogs, using crimped synthetic prostheses. In most of the grafts thromboses developed as soon as they had been anastomosed by suture techniques, thrombi being frequently attached to the suture lines. On the basis of these observations, it seemed likely that a non-suture technique which avoided intimal damage might lower the incidence of early thrombosis. The other type of occlusion, late occlusion, had been observed in a dog with thoracic inferior vena cava replacement in which a synthetic pliable graft had been used. The prosthesis had maintained long-term patency, but the animal developed ascites. At necropsy, the prosthesis was found collapsed and constricted by surrounding tissue proliferation.

Therefore, we studied several types of prosthesis for venous replacement. The prostheses had some rigidity to resist external pressure and various degrees of porosity and coatings or linings of the inner surface. They were grafted into the thoracic or abdominal inferior vena cava of dogs by non-suture techniques.

This paper describes mainly the necessity of a rigid prosthesis and the utility of non-suture technique for venous replacement. More details in regard to the porosity, coating and lining, readers are reported in my coworker YAMAMOTO's paper⁶⁾.

II EXPERIMENTAL MATERIALS AND METHODS

Preparation of the prosthesis :

The prostheses used were 2.5 to 3.0 cm in length and 7 to 12 mm in diameter. Tubular pieces of woven Tetoron (polyethylene telephthalate, identical with Dacron) and Tevion (polyvinyl chloride) were prepared. Cylinders of rolled paper with diameters equal to the veins to be grafted were inserted through the tubular materials and treated with heat over a low fire from a gas range. They shrank and hardened immediately to form rigid tubes. Then both ends of the tubes were folded back and reinforced (Fig. 1). Rigid tubes of Tetoron mesh (Fig. 2) were prepared for more rigid and porous prostheses.

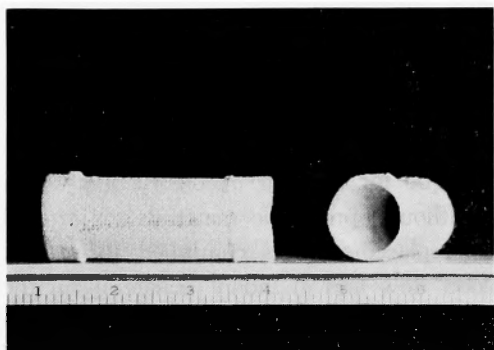


Fig. 1 A rigid prosthesis of woven synthetic material. The ends are folded back and reinforced.

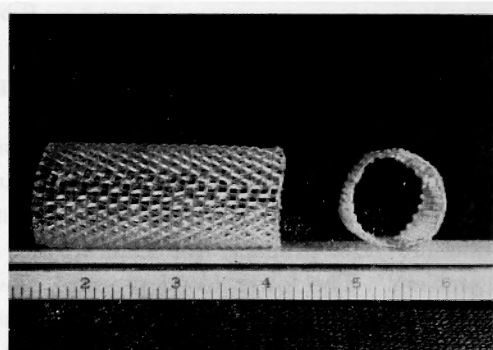


Fig. 2 A rigid tube of Tetoron mesh used for a base for lining. It is woven from 1,000 Denier of Tetoron monofilament.

Coating or lining on the inner surface of the prostheses :

Three types of prostheses were prepared.

1) Rigid tubes of synthetic woven materials were coated with simple gelatin or heparin-containing gelatin as described by BASCON⁷⁾ and YAMAMOTO⁸⁾. They were immersed in warmed 7% simple gelatin solution or gelatin solution containing 1,000 unit of heparin in each 10 ml of 7 % gelatin.

2) Homologous-vein-lined prostheses were prepared as follows. Pieces of fresh homologous veins were removed aseptically from the thoracic or abdominal inferior vena cava of other dogs. Rigid tubes of Tetoron mesh were as a base into which the removed veins were inserted and then both ends of the veins were folded back and held in place with fine silk ligatures (Fig. 3).

3) Synthetic-fabric-lined prostheses were prepared in the same manner. Rigid Tetoron mesh tubes were lined with tubular Tetoron, Tevion or Polyflon (Teflon) fabrics.

Before use, all except the homologous-vein-lined prostheses were sterilized with heating (120°C for two hrs.) or autoclaving.

Experimental methods :

Adult mongrel dogs of both sexes weighing 7 to 15 kg were anesthetized with intravenous pentobarbital sodium. The thoracic inferior vena cava was exposed through thoracotomy in the right seventh intercostal space under controlled respiration with oxygen.

Exposure of the abdominal inferior vena cava below the renal veins was performed through midline laparotomy. The thoracic or abdominal inferior vena cava was dissected and isolated from the pleura or peritoneum and surrounding tissue. Then a pair of forceps was inserted to provide hemostasis during anastomosis. The forceps were specially devised for occlusion of veins. As shown in Fig. 4, they consist of a pair of forceps with wide blades and elastic handles and are joined and fixed with a bar. The vein was transected after the occluding forceps had been set and each of the two cut edges three ligatures were applied in a triangular fashion. Then the prosthesis was grafted by non-suture technique, as illustrated in Fig. 5.

A prosthesis of appropriate size corresponding to the diameter of the vein was chosen. One of the cut ends of the vein which was dilated with the three placed ligatures was advanced over the outside of the prosthesis and bound in place with one or two silk ligatures. The other end of the vein was anastomosed in the same way over the other end of the prosthesis. Before completion of the anastomosis, saline was infused to the prosthesis. After release of the occluding forceps, vascular continuity was restored without leakage or narrowing of the blood flow. In these procedures the vena cava was occluded for 9-30 minutes (average 14 minutes). As a general rule, phlebograms were taken one or two weeks postoperatively. The surviving dogs were killed at various interval and the grafted veins were removed and examined for patency and histological findings. The microscopic sections were stained with hematoxylin-eosin and elastica-van Gieson's solution. During the course of examinations, three long-term survivors (No. 42, 52 and 58) were sacrificed and the small blood vessels, especially the arterioles and the capillaries, of the organized prostheses were stained with

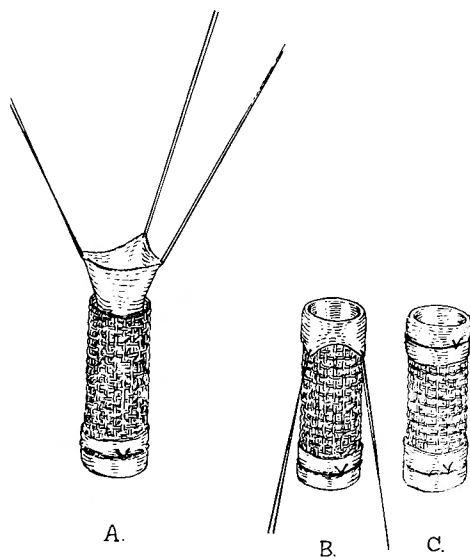


Fig. 3 shows the technique of preparing a homologous vein-lined prosthesis.

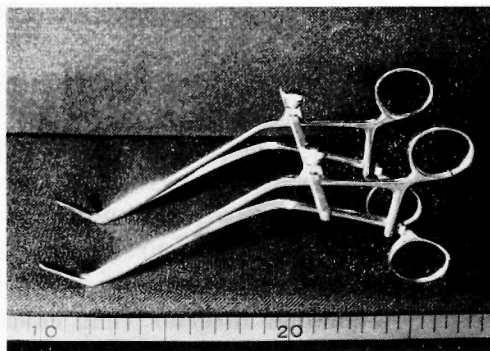


Fig. 4 Specially devised occluding forceps. A pair of forceps are joined with a bar. Note wide blades and slender handles.

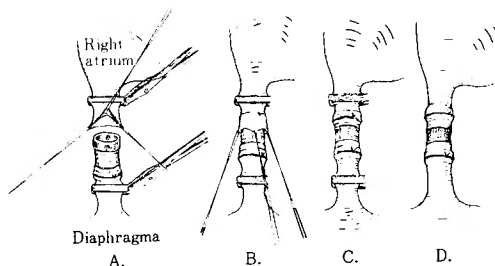


Fig. 5 shows the technique of the nonsuture method. After the intrathoracic inferior vena cava has been occluded with forceps and divided, a rigid prosthesis is inserted into both ends of the vein and tied with silk ligatures. Note support of three stay sutures to dilate the vein.

india ink and clear preparations were made.

III EXPERIMENTAL RESULTS

Results of 51 graftings are summarized in Tables 1 and 2 : 40 of the thoracic inferior vena cava and 11 of the abdominal vena cava. Six dogs died immediately after the operation and are excluded.

1. Thoracic inferior vena cava grafting :

On the basis of length of survival, the 40 dogs were divided into three groups : Group-A, 8 dogs (20%) died within 2 weeks after the operation ; Group-B, 16 dogs (40%) survived 2 weeks to 3 months ; Group-C, 16 dogs (40%) survived longer than 3 months and were sacrificed 5-12 months after grafting.

In this series there were evident that the first, the occlusion or stricture of the grafted prostheses caused death or ascites and the second, the length of survival depended on the type of occlusive change. Occlusions caused by clot formation (early thrombosis) occurred within 2 weeks after the grafting and caused death (Group-A). When no early thrombosis occurred, the animal survived at least 2 weeks. Narrowing of the grafted prosthesis or a septum-like stricture at the site of anastomosis in the host vein occurred after 2 weeks to 3 months and caused ascites or death (Group-B). If no occlusive change had occurred within 3 months, the animal survived indefinitely and the grafting was completed satisfactory (Group-C).

In Group-A, dog No. 7 died with early thrombosis. In Group-B, 3 dogs died with complete obstruction of the prosthesis and 10 with narrowing and / or thrombosis of the prostheses ; the other 3 dogs died accidentally. In Group-C, all prostheses remained patent. Dog No. 58 was sacrificed 2 1/2 months after the grafting, and the prosthesis was found patent and well healed, so the animal was included in Group-C.

The patency rate of 40 thoracic inferior vena cava grafting was therefore 16/40 (40%) (Group-C).

2. Abdominal inferior vena cava grafting :

Of the 11 grafts of the abdominal inferior vena cava, only one remained patent for more than 3 months. The patent prosthesis of dog No. 64 had been prepared from Tetoron mesh and homologous vein lining. In this series, the three patent prostheses 2 weeks to 5 months after grafting were all homologous-vein-lined Tetoron mesh.

The patency rate was 1/11 (9 %).

Results of prosthetic materials :

In these experiment, Tevion (polyvinyl chloride), Tetoron (Dacron) and Polyflon (Teflon) were used for the prostheses and there were no significant difference in patency rate between these materials.

Effect of coating or lining :

In the thoracic inferior vena cava grafts, the effect of coatings or linings of the prostheses on the survival rate is shown in Table 3. Coating with heparin-containing gelatin solution failed to have the desired effect on early thrombosis, but lining with homologous vein was effective. In both thoracic and abdominal grafts, homologous-vein-lined prostheses showed better patency, because no early thrombosis occurred and the incidence of occlusions, such as thickening of the homologous vein or septum-like stricture at the site of anastomosis

was relatively low (Figs. 6 and 7). A more detailed description of the coatings and linings is available in YAMAMOTO's paper⁶⁾.

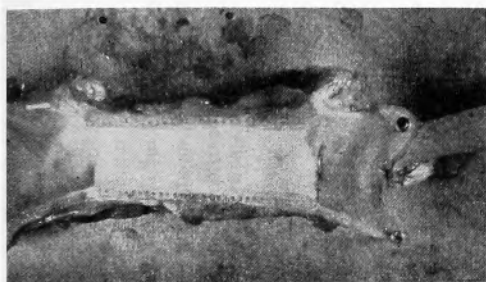


Fig. 6 Homologous vein-lined Tetoron mesh grafted into the the thoracic inferior vena cava of dog No. 55 ; 10 months after operation.

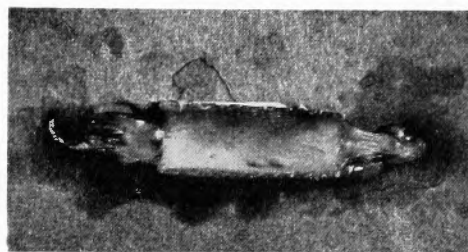


Fig. 7 Homologous vein-lined Tetoron mesh grafted into the abdominal inferior vena cava of dog No. 64 ; 5 months after operation.

Effect of rigid prosthesis :

Prostheses with various degrees of rigidity were used in this study. A less rigid and slightly pliable prosthesis of Tevicon and a pliable crimped prosthesis of Tevicon were grafted into the thoracic inferior vena cava in dogs No. 15 and No. 33. Figs. 8 and 9 show the autopsy findings. The middle portion of the prosthesis of dog No. 15 in which both ends were folded back and reinforced was narrowed and constricted by scar tissue. Both sites of anastomosis in the prosthesis of dog No. 33 showed constriction. There was, however, no evidence of flattening or narrowing of prostheses which had been prepared to be more rigid and less pliable (Fig. 10).

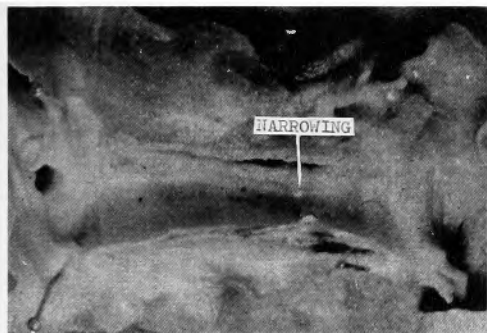


Fig. 8 Semi-rigid Tevicon prosthesis grafted into the thoracic inferior vena cava of dog No. 8. The animal developed severe ascites and died 6 months after grafting. The middle portion of the prosthesis is narrowed, but both ends remain widely open because of the reinforcement.

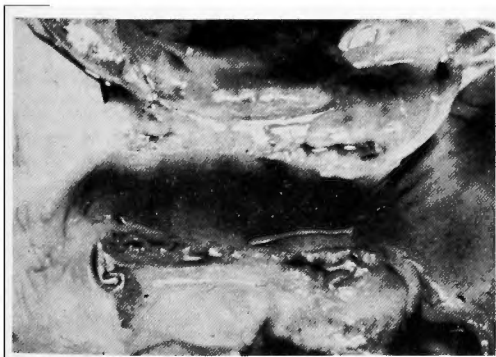


Fig. 9 Pliable crimped Tevicon prosthesis grafted by suture technique into the thoracic inferior vena cava of dog No. 33 ; 9.5 months after grafting. Both ends of the prosthesis are constricted.

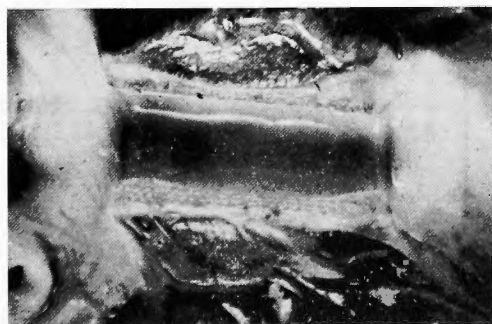


Fig. 10 Rigid Tevicon prosthesis grafted into the thoracic inferior vena cava of dog No. 29 ; 10 months after grafting. The prosthesis remained widely patent and well-healed.

Table 1 Summary of Thoracic Inferior Vena Cava Graftings

Group	Dog No.	Period Follow.	Cause of Death	Prosthesis		Anastomosis		Result			Remarks
				Material	Rigidity	Technique	Ease of performance	Patency	Thrombosis	Stricture	
A	37	2 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	Died at Cavography
A	7	3 Days	Accid. Death	Teviron	Semirigid	Nonsuture	Difficult	Patent	Thrombosed	No	
A	34	3 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
A	14	4 Days	Died	Teviron	Semirigid	Nonsuture	Difficult	Occlud.	Thrombosed	No	
A	36	6 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
A	45	7 Days	Died	Polyfulon lined Tetoron Mesh	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
A	38	10 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
A	20	13 Days	Died	Teviron	Semirigid	Nonsuture	Easy	Occlud.	Thrombosed	No	Ascites
B	13	14 Days	Accid. Death	Teviron	Semirigid	Nonsuture	Easy	Patent	No	No	
B	30	14 Days	Accid. Death	Teviron	Rigid	Nonsuture	Easy	Patent	No	No	
B	51	14 Days	Accid. Death	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	No	
B	9	19 Days	Died	Teviron	Semirigid	Nonsuture	Difficult	Patent	No	##Septum	
B	35	20 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
B	43	20 Days	Died	Teviron	Rigid	Nonsuture	Easy	Patent	Thrombosed	+Septum	
B	44	22 Days	Died	Teviron	Semirigid	Suture	(Difficult)	Occlud.	Thrombosed	+Septum	
B	48	25 Days	Died	Polyfulon lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	Thrombosed	No	
B	10	26 Days	Died	Teviron	Pliable	Nonsuture	Easy	Patent	Thrombosed	##Collapse	
B	22	27 Days	Died	Teviron	Pliable	Nonsuture	Easy	Occlud.	Thrombosed	##Partially Constricted	
B	41	30 Days	Died	Teviron	Rigid	Nonsuture	Easy	Patent	Thrombosed	+Septum	
B	25	36 Days	Died	Teviron	Rigid	Nonsuture	Difficult	Patent	No	##Septum	
B	19	39 Days	Died	Teviron	Semirigid	Nonsuture	Easy	Patent	No	##Septum	
B	47	41 Days	Died	Polyfulon lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	Thrombosed	+Septum	
B	39	2 Mon.	Died	Teviron	Rigid	Nonsuture	Easy	Patent	Thrombosed	##Septum	
B	15	2.5 Mon.	Died	Teviron	Pliable	Nonsuture	Easy	Patent	No	##Collapse	

C	58	2.5 Mon.	Sacr.	Tetoron lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	No	
C	46	5 Mon.	Sacr.	Polyfulon lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	No	
C	52	5 Mon.	Sacr.	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	No	No	
C	8	6 Mon.	Sacr.	Teviron	Semirigid	Nonsuture	Difficult	Patent	No	No	
C	59	6.5 Mon.	Sacr.	Tetoron lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	+Thickening of Neointima	Ascites
C	42	8 Mon.	Sacr.	Teviron	Rigid	Nonsuture	Easy	Patent	No	#Septum	Ascites
C	56	8 Mon.	Sacr.	Tetoron lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	No	#Septum	
C	33	9.5 Mon.	Sacr.	Teviron Crimped	Semirigid	Suture	(Difficult)	Patent	No	+Partially Constricted	
C	27	10 Mon.	Sacr.	Tetoron Crimped	Phable	Suture	(Difficult)	Patent	No	+Collapse	
C	29	10 Mon.	Sacr.	Teviron	Rigid	Nonsuture	Difficult	Patent	No	No	
C	55	10.5 Mon.	Sacr.	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	No	No	
C	57	10.5 Mon.	Sacr.	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	No	
C	11	11 Mon.	Sacr.	Teviron	Semirigid	Nonsuture	Easy	Patent	Thrombosed	#Septum	
C	23	11 Mon.	Sacr.	Teviron	Semirigid	Nonsuture	Easy	Patent	No	No	
C	26	11 Mon.	Sacr.	Teviron	Semirigid	Suture	Difficult	Patent	No	+Partially Constricted	
C	12	12 Mon.	Sacr.	Teviron	Semirigid	Nonsuture	Difficult	Patent	No	+Partially Constricted	

Table 2 Summary of Abdominal Inferior Vena Cava Graftings

Dog No.	Period Follow.	Cause of Death	Prosthesis		Anastomosis		Result			Remarks
			Material	Rigidity	Technique	Ease of performance	Patency	Thrombosis	Stricture	
60	4 Days	Died	Teviron lined Tetoron Mesh	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	Infection
31	5 Days	Died	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
53	7 Days	Sacr.	Teviron	Rigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
32	12 Days	Sacr.	Teviron	Rigid	Nonsuture	Difficult	Occlud.	No	##Septum	
65	14 Days	Accid. Death	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	No	No	Infection 10 Days Cavogram patent
62	14 Days	Sacr.	Teviron	Semirigid	Nonsuture	Easy	Occlud.	Thrombosed	No	
28	17 Days	Sacr.	Teviron	Rigid	Nonsuture	Easy	Occlud.	No	##Septum	
54	19 Days	Died	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Difficult	Patent	No	No	
63	2.5 Mon.	Sacr.	Teviron	Semirigid	Nonsuture	Easy	Occlud.	Thrombosed	##Collapse	
61	3 Mon.	Sacr.	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Easy	Occlud.	No	##Septum	
64	5 Mon.	Sacr.	Homol. Vein lined Tetoron Mesh	Rigid	Nonsuture	Easy	Patent	No	No	

Table 3 Relationship between survival rate and coating or lining on inner surface of prostheses in thoracic inferior vena cava

Coating or Lining		Duration of Survival		
		Less than 2 Weeks Group-A	From 2 Weeks to 3 Months Group-B	Over 3 Months Group-C
None	15	2 (13%)	4 (27%)	9 (60%)
Gelatin Coating	1	1	0	0
Heparin-Gelatin Coating	20	5 (25%)	11 (55%)	4 (20%)
Homologous Vein Lining	4	0	1 (25%)	3 (75%)
Total	40	8 (20%)	16 (40%)	16 (40%)

Effect of non-suture technique :

Of the 40 thoracic inferior vena cava grafts, 36 were inserted by non-suture techniques and 4 by suture techniques. The 11 intraabdominal grafts were all anastomosed by non-suture techniques. The average time required for non-suture anastomoses was 14 minutes and required much shorter occlusion time than did the suture technique, which required an average occlusion time of 34 minutes. In the non-suture technique, the sites of anastomosis in the host veins were dilated, and after the release of the occluding clamps blood was transported without leakage or narrowing, and damage of the intima was minimal. Grafts of homologous-vein-lined prostheses provided an intima-to-intima apposition. All the prostheses inserted by non-suture techniques were well anastomosed and healed except in two instances (No. 53 and No. 62) in which the prostheses become infected. The infected prostheses were occluded and displaced in spite of being bound in place with silk ligatures. The healing process of non-suture anastomoses is shown in Figs. 11, 12 and 13. The bindings with silk ligatures were initially surrounded by connective tissue and thereafter they cut into the wall of the veins. Figs. 12 and 13 show that the silk ligatures are transecting the elastic fibers gradually and they reach the prosthesis and heal.

In a majority of the instances of late occlusion, there were characteristic septum-like constrictions at the sites of anastomosis in the host vein. The septum formations were occurred



Fig. 11 shows microscopic appearance of non-suture anastomosis. Tevion prosthesis grafted in dog No. 15 ; 2.5 months after grafting. Elastica staining.

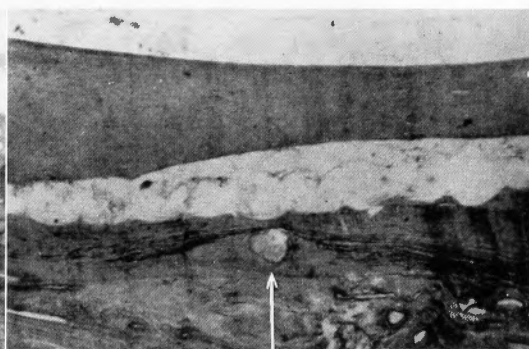


Fig. 12 Microphotograph of dog No. 15 ; 2.5 months after non-suture anastomosis. The silk ligature is cutting into the elastic fibers of the vein wall.



Fig. 13 Microphotograph of dog No. 22 ; 27 days after non-suture anastomosis. The silk ligature has transected the elastic fibers (arrowed).



Fig. 14 Septum-like constriction at proximal site of anastomosis (left). A white thrombus extends from the cusp of the septum toward the right atrium. Dog No. 41, 30 days after grafting.



Fig. 15 Microphotograph showing septum formation. Dog No. 22, 27 days after grafting. Thickening and wrinkling of the intima of the host vein forms a protrusion at the site of anastomosis. The blood stream struck it, and a thrombus which formed on the surface of the prosthesis extending upward along the ascending current like a cornice formation.

mostly at the proximal ends of the thoracic inferior vena cava and often tape-like white thrombi extended from the cusps of the septum toward the right atrium (Fig. 14). The origin of the septum is clearly seen in Fig. 15. Marked thickening and wrinklins of the intima of the host vein takes place at the site of anastomosis and protrudes towards the inside of the prosthesis. The blood stream strikes the protrusion, and a thrombus forms and extends upward along the ascending current as a cornice formation. In 16 prostheses in Group-B, 10 occlusions were caused by septum formation.

IV DISCUSSION

The results of this study suggest that some of the prime requirements for venous prostheses are rigidity and a non-suture method of anastomosis. In 1952, DANIEL⁸⁾, using a plastic tube as a canine portal vein graft, revealed the speed and simplicity of non-suture anastomosis, but his results showed a poor patency rate. In 1956, EGDAHL and HUME⁹⁾ first applied non-suture venous grafts with homologous-vein-lined polyethylene tubes, and they emphasized the importance of external vascularization through the perforations. BENVENUTO and LEWIS¹⁰⁾ used a plastic ring as an external support to prevent the collapse of venous anastomosis. EAST and MULLER¹¹⁾ suggested as a major requirement for venous prostheses the use of semi-rigid tubes, and ALLANSMITH¹²⁾ used a Teflon graft supported with rigid plastic rings on a clinical case of superior vena cava replacement. The first devices for non-suture anastomoses were reported by BLAKEMORE and his associates¹³⁾ in 1943. They used vein-lined vitallium cuffs in portacaval and splenorenal shunt operations. Since then, several authors have discussed the advantages and disadvantages of non-suture techniques¹⁴⁾¹⁵⁾.

Since 1963, we have often suggested the desirability of a rigid prosthesis as a venous prosthesis in The Japanese Society For Artificial Organs and Tissues¹⁶⁾¹⁷⁾ and more recently we have successfully applied the non-suture technique using Tetolon mesh tubes as venous anastomoses for orthotopic liver transplantation in dogs¹⁸⁾.

The utility and feasibility of the non-suture technique were evaluated in this study and it seems satisfactory because of its speed, simplicity, lack of leakage and excellent healing. In groups B and C which survived for at least 2 weeks, the fate of the non-suture anastomoses is shown in Figs. 11, 12 and 13. The placed and tied silk ligatures around the venous walls and the rigid prostheses gradually cut into the venous wall, but they healed well and become organized. In spite of my original fears, there was no instance of leakage at the site of anastomosis except in a few infected prostheses. In the successful cases, the lining of the neointima was smoothly continuous with the intima of the veins, and the outsides of the prostheses were tightly enveloped and surrounded by scar tissue.

The use of rigid tube as a venous prosthesis appears to be a major requirement. Most of the pliable and less rigid prostheses showed collapse or narrowing of the lumen, but the lumen in the rigid prostheses remained as widely patent as at the time of grafting. One requirement for vascular prostheses as stated by some authors¹⁹⁾²⁰⁾²¹⁾ is porosity. To meet this requirement, rigid prostheses were prepared from woven material of various grades of porosity. From this point of view, the good result of the non-suture anastomosis

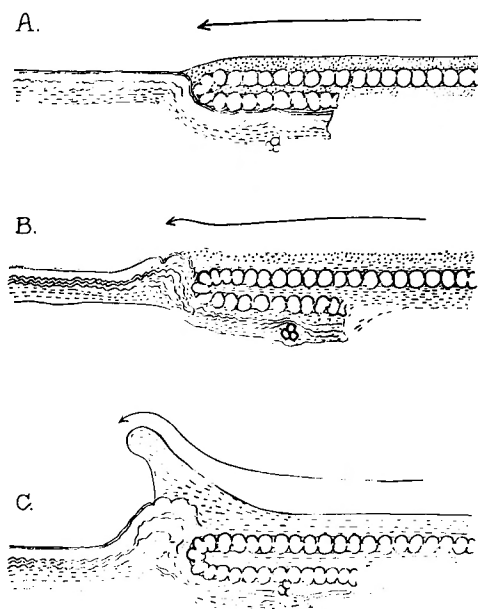


Fig. 16 illustrates the process of septum formation schematically.

might be obtained by the use of porous synthetic tube, while BLAKEMORE's cuff-method¹³⁾ had used a solid vitallium tube.

The healing properties in relation to the porosity and treated surfaces of these prostheses are further discussed in YAMAMOTO's paper⁶⁾.

The incidence of septum like strictures, which were found at the sites of anastomosis in the veins, was relatively high. These septum formations occurred from 2 weeks to 3 months after the grafting, and they often caused the death of the animals in group B. The microscopic findings in the dogs in groups B and C (surviving for at least 2 weeks) showed that the stage of septum formation corresponded to the healing stage of the prosthesis. Which types of prostheses are apt to induce septum formation? A careful review of my data indicates that some of the methods of treating the surfaces of the prostheses, some coatings or linings, could prevent early thrombosis but not later septum formation. The problem of septum formation in some prostheses which have the same rigidity and are grafted with the same non-suture technique as others in which no septum forms remains unsolved. On the basis of the observations on aortic grafts in growing pigs, WESOŁOWSKI, FRIES and SAWYER discussed the mechanism of septum formation²²⁾. They considered that the poor blood supply through the interstices of a graft of low porosity develops degeneration of the granulation which layered on the inner surface and it attracts deposit of fibrin growing to a septum. There are some disagreements between their observations and my data. Figs. 15 and 16 illustrate the process of septum formation microscopically and schematically. After the grafting, a bellows-like shrinkage or thickening takes place in the venous wall at the anastomosis and continues into the grafted prosthesis, causing an infolding into the lumen. The blood stream through the vein and prosthesis strikes the protrusion, and a septum-like thrombus grows in the way a snowstorm forms a cornice on the ridge of a mountain. The microphotograph (Fig. 15) shows that the septum was not caused by ischemic degeneration of the inner capsule, but by thickening of the media of vein.

On the basis of these findings it might be inferred that if the bellows-like shrinkage of the venous wall could be avoided by a tense non-suture anastomosis, the incidence of septum formation would be further decreased. When the diameters of the vein and the prosthesis were very similar, the insertion of the prosthesis into the venous lumen aggravated the difficulty and extended the occlusion time. In the cases in which anastomosis was difficult, the venous wall at the sites of anastomosis were usually subjected to higher tension both radially and axially. The difficulty of the procedure may be expressed in terms of occlusion time. A relationship between the incidence of septum formation and difficulty of anastomosis is shown in Table 4. The data indicates that the incidence of septum formation is twice as high in the easily anastomosed cases as in the difficult cases. It appears probable, therefore, that a tense non-suture anastomosis would prevent septum formation.

In this study, the thoracic inferior vena cava grafts remained patent for over 3 months in 16/40 (40%), but the abdominal inferior vena cava grafts in only 1/11 (9%). The difference in patency between the thoracic and abdominal inferior vena cava grafts may be due to the negative intrathoracic pressure and abundant blood flow from the kidneys and liver, while the intrabdominal pressure tends reduce blood flow²³⁾. The one patent

Table 4 Relationship between incidence of septum formation and difficulty of grafting in 28 dogs surviving at least 2 weeks (Groups B and C) after thoracic inferior vena cava grafting with non-suture technique

		Difficulty of Procedure	
		Easy	Difficult
Cases with little or no Septum Formation	19	10 (47%)	9 (53%)
Cases with definite Septum Formation	9	7 (78%)	2 (27%)

remained abdominal graft was homologous-vein-lined prosthesis, which encourages the author to continue further experiments. He anticipates that an ideal surface treatment of a rigid tube will provide more excellent results.

When can a venous graft be judged to be successful? Numerous reports on the patency of venous grafts have been published by many authors²⁴⁾⁻⁴¹⁾. The data on various observation times and the use of various materials indicate that the patency rates in animals surviving for at least 3 months have been 30% or less. The patency rates in this study were all obtained after at least 3 months of observation, and are therefore relatively high. The author's opinion is that the success of venous grafts must be judged after an observation period of at least 3 months, because process of late occlusion may require as long as 3 months.

V SUMMARY AND CONCLUSION

1. Rigid prostheses prepared from synthetic woven material were grafted into the thoracic inferior vena cava of 40 dogs and into the abdominal inferior vena cava of 11 dogs. Most graftings were performed by non-suture techniques. The results of follow-up studies are reported.

2. The long-term patency rate in dogs surviving at least 3 months was 16/40 (40%) for thoracic inferior vena cava grafts and 1/11 (9%) for abdominal inferior vena cava grafts.

3. Two types of occlusion, early thrombosis and late occlusion, were noted in venous grafts. The early thrombosis occurred within 2 weeks and the late occlusion from 2 weeks to 3 months after grafting. The former depends on the anastomosing technique or surface property of the prosthesis and the latter is caused by scar formation around the graft which leads to collapse and constriction.

4. The utility and feasibility of non-suture techniques proved satisfactory but their prevention of early thrombosis could not be clarified.

5. A rigid venous prosthesis is necessary as an external support. Rigid prostheses maintained the lumen well and remained patent, while the less rigid and pliable prostheses tended to collapse and become constricted.

6. A type of late occlusion, septum formation, was found at the site of anastomosis in the venous wall. It originates from an organized thrombus which grows upon a protrusion of the venous wall. It is suggested that a tense non-suture anastomosis between the vein and the rigid prosthesis may decrease the incidence of this septum formation.

7. If early thrombosis can be prevented by the further development of better surface

properties, more satisfactory results can be expected in venous grafting with the use of a rigid prosthesis which supports the lumen against late occlusion.

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和文抄録

静脈移植に関する実験的研究

特に硬化管の使用及び挿入固定吻合法について

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静脈用の人工血管は動脈用の人工血管と異なるものでなければ成功は望み得ないとの見地から、種々の平織り合成線維による硬化管を作製し、縫合を行わない挿入固定法によつて成犬51頭の胸腔及び腹腔内の下大静脈に移植した。本論文においては主に、移植管の硬度の必要性と、挿入固定吻合法の有用性について検討した。使用した合成線維はテトロン、テビロン（塩化ビニール）、ポリフロン（国産テフロン）が主であつて、これらに熱処理を加えて種々の硬度のものを作製し、また硬いテトロン網状管も使用した。これらの管に内面処理としてゼラチン単独、ヘパリン加ゼラチン塗布、同種新鮮静脈の内被化等を行なつた。

1. 平織り合成線維硬化管の3ヵ月以上にわたる長期開存率は、胸腔内下大静脈において16/40（40%）であり、腹腔内下大静脈においては1/11（9%）であつた。

2. 移植管の閉塞様式には早期血栓性閉塞と、晩期閉塞の2種類が観察された。早期血栓性閉塞は移植後間もなくより、遅くとも2週間以内に発生し、管腔の内面処理が関与して、同種静脈による内被管が最も優れていた。晩期閉塞は移植後2週間より3ヵ月の間に発生して、その原因は移植管を取捲く結合組織増殖のための管腔圧迫及び吻合部における隔壁様物の発達

による閉塞である。移植後3ヵ月を過ぎると閉塞は起らず、静脈移植の開存性を立証するには最短3ヵ月以上の観察を必要とする。

3. 挿入固定による無縫合吻合法は、血流遮断時間の短縮、吻合部狭窄を来さないこと、静脈内膜の損傷を来さないこと、血液の漏出のないこと等の優れた特徴を有しており、当初において危惧せられた糸による緊縛部静脈壁の壊死と、それによる吻合不全は全くみられず、その有用性が立証された。しかし期待された早期血栓防止に対する卓越性は立証出来なかつた。

4. 移植管の硬度は挿入固定吻合法を行なう際には必要であり、晩期の外周よりの圧迫性狭窄または閉塞に抗するためにも必要と考える。

5. 晩期閉塞の1様式である吻合部の隔壁様物による閉塞は、吻合部静脈壁の肥厚及び収縮によつて生じた内腔への突出に対して衝突する血流により発生した器質化血栓によるものであることを明かにし得た。これの防止策としては緊張ある吻合が、その発生を或程度減少させ得るものではないかと考える。

6. 将来の静脈用人工血管には、早期血栓性閉塞対策として血管の内膜面に似た内面処理の必要性と、晩期閉塞に対する硬度が要求せられるものと考えられた。